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Silicon Processing

for the VLSI Era
Volume 1 – Process Technology

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SILICON PROCESSING

FOR

THE VLSI ERA

VOLUME 1:

PROCESS TECHNOLOGY

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BASICS OF THIN FILMS

A large variety of "thin films" are used in the fabrication of VLSI devices. These films may be thermally grown or deposited from the vapor phase. They can be metals, semiconductors, or insulators. Figure 1 shows a cross-section of an advanced CMOS device illustrating some of the instances in which thin films are used. Since thin films are so important to VLSI devices, an understanding of their chemical and physical properties leads to a better understanding of their behavior in devices.

Thin films for use in VLSI fabrication must satisfy a large set of rigorous chemical, structural, and electrical requirements. Film composition and thickness must be strictly control-led to facilitate etching of submicron features. Very low densities of both particulate defects and film imperfections, such as pinholes, become critical for the small linewidths, high densities, and large areas necessary for VLSI. These small geometries also create highly rugged topography for overlying films to cover. Therefore, excellent adhesion, low stress, and conformal step coverage are required of a VLSI thin film, and its own surface topography should reduce or even planarize the underlying steps if possible. Finally, non-conducting thin films must have low dielectric constants to reduce parasitic capacitances exacerbated by the scaled down film thicknesses.

Although the properties of a bulk material may be well characterized, the same material in its thin film form may have properties substantially different from those of the bulk. One reason is that thin film properties are strongly influenced by surface properties, while in bulk materials this is not the case. The thin film, by its very definition has a substantially higher surface-to-volume ratio than does a bulk material. The structure of thin films, and their method of preparation also play a vital role in determining the film properties.

The formation of such films is accomplished by a large variety of techniques (which are the subject of subsequent chapters), but which can conceptually be divided into two groups: 1) film growth by interaction of a vapor-deposited species with the substrate; and 2) film formation by
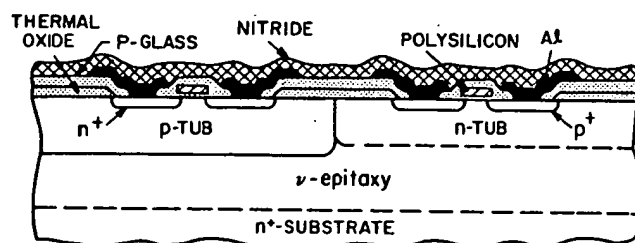

Fig. 1 Examples of types of thin films used in VLSI fabrication[14]. (© 1980 IEEE.)

deposition without causing changes to the substrate material. The first category includes thermal oxidation and nitridation of single crystal silicon (Chap. 7) and polysilicon (Chap. 6), and the formation of silicides by direct reaction of a deposited metal and the substrate (Chap. 11).

The second group includes another three subclasses of deposition: a) chemical vapor deposition, or CVD, in which solid films are formed on a substrate by the *chemical* reaction of vapor phase chemicals that contain the required constituents; b) physical vapor deposition, or PVD, in which the species of the thin film are *physically* dislodged from a source (to form a vapor), which is transported across a reduced pressure region to the substrate, where it condenses to form the thin film; and c) coating of the substrate with a liquid, which is then dried to form the solid thin film. When CVD process are used to form single-crystal thin films, the process is termed *epitaxy* and is the subject of Chap. 5. The formation of amorphous and polycrystalline thin films by CVD is discussed in Chaps 6 and 11. The formation of thin films by PVD includes the processes of sputtering and evaporation (Chap. 10), and molecular beam epitaxy (Chap. 5). The deposition of a liquid on a substrate to form thin films, most commonly by spin-coating, is discussed in Chap. 12 as part of the photoresist process presentation.

The purpose of this chapter is to discuss the terminology and properties common to thin films in general. That is, basic background information on the growth mechanism, structure, mechanical properties, and electrical properties of thin films is provided for readers not well acquainted with materials science concepts. By defining these properties in a stand-alone chapter, it is not be necessary to repeat this information each time a new thin film deposition method is introduced. The specific formation and associated processing of particular films is described in detail in later chapters.

THIN FILM GROWTH

Thin films are most commonly prepared by condensation of atoms or molecules from the vapor phase. This implies that during formation, a change of phase from the vapor to the solid occurs (also termed *condensation*). Deposition on a substrate different from the film requires the consideration of a third phase (i.e. that of the adsorbed atoms which have not yet combined with other adsorbed atoms). Condensation is initiated by the formation of small *clusters* (or *nuclei*) through the random agglomeration of several adsorbed atoms. The enlargement of these nuclei to form a coherent film is termed *growth*. Often nucleation and growth can occur simultaneously during film formation. The growth of thin films is discussed in detail in many standard reference works (e.g. Maissel and Glang[1], and Chopra[2]).

Thin Film Nucleation

The condensation of vapor atoms requires that attraction occurs as the vapor atoms impinge upon the surface. Either dipole or quadropole attractive forces can result in an atom becoming attached to the surface (which after becoming attached to the surface, is then referred to as an *adatom*). In order to undergo attachment, the atom must transfer the normal component of its velocity to the surface. If the attachment occurs without a transfer of electrons, the adsorption mechanism is known *physisorption*, while if electrons *are* transferred, it is termed *chemisorption*. The binding energies associated with physisorption are typically much smaller than those of chemisorption (i.e. ~0.25 eV vs. 8-10 eV). Adsorbed atoms may continue to move along the surface by jumping into other positions (i.e. by moving from potential well-to-potential well), as a result of the kinetic energy associated with their initial lateral velocity, or by thermal